MODELING OF NAVY POSTGRADUATE PERSONNEL SYSTEMS FOR OPTIMIZATION OF EDUCATION PLANS

by

Lyman Edward Krekel

United States Naval Postgraduate School

THESIS

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Lyman Edward Krekel
Lieutenant Commander, United States Navy
B.A., University of Iowa, 1956

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ABSTRACT

A descriptive model of personnel systems existent in the U. S. Navy for acquisition and utilization of officers with postgraduate education is presented in this report. Relations are established between advanced technical/managerial billet levels, personnel requirements levels, expected personnel inventory levels and postgraduate enrollment schedules. The criterion for selection of an optimal postgraduate enrollment schedule from the set of acceptable schedules which satisfy the system relations is prescribed to be the minimization of net present cost of personnel system operation.

Computational programs based on the mathematical structure of the model developed will provide valuable information to personnel management on expected personnel shortages and critical seniority levels. Personnel management will also be afforded a capacity to rapidly evaluate the effects of changes in continuation rates, program costs and alternative management policies on postgraduate program enrollment plans.

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I. INTRODUCTION

Navy management has long recognized that certain military positions (billets) require the officer incumbent to posses an advanced technical/managerial knowledge in addition to his professional naval qualifications. Policies and procedures for identification of billets with advanced education requirements exist in the Navy. The identified billets are known as "P-coded billets" where, in addition to specification of the rank and the professional naval qualifications of a prospective incumbent, the academic area is specified in which advanced education is desired for qualification. For example, a billet with a code "8501P" specifies that an incumbent officer should have completed advanced study in the field of Operations Research/Systems Analysis. This code is additional to specification of a professional specialty, such as naval aviator, surface line officer, supply officer, etc., and the seniority qualifications of a prospective incumbent.

This billet-designation process has imposed a requirement on officer personnel management to maintain an "accounting" system for identification of officers with advanced technical/managerial expertise for assignment purposes. The identification is achieved by assigning "P-codes" to officers who posses advanced educational qualifications in an academic area by a coding identical to that used for designation of advanced technical/managerial billets. Thus, an officer who has completed a prescribed program of study in Operations Research or

Systems Analysis is identified by assignment of the code 8501P to his record of qualifications.

The advanced education prerequisite to qualification for P-code designation is beyond the level of baccalaureate degrees held by most officers on entry into the service. Therefore, the number of P-coded billets identified in the service has far exceeded the number of officers who posses advanced educational qualifications based on postgraduate study previous to commissioning. This advanced education is also not normally acquired in general professional assignments. Without some means of providing postgraduate education to officers on active duty, or a special recruitment program for acquisition of naval officers with advanced degrees, the inventory of P-coded personnel would be insufficient to fill the P-coded billets.

The Navy has adopted a postgraduate study program for naval officers on active duty for acquisition of an inventory of personnel with the advanced technical/managerial qualifications. A goal of this program is to provide "sufficient" numbers of P-coded personnel in the active inventory to meet the identified billet requirements. Personnel management is provided resources in the form of budgetary funding and manpower for utilization in the postgraduate programs. Within broad restraints, personnel management has control over how these resources are expended in the acquisition of adequate numbers of qualified personnel and assignment to service in P-coded billets.

How many officers should be assigned to postgraduate study each year? What seniority should officer students have on entry into a postgraduate program? What is the relation between enrollment of an officer in a postgraduate program and the P-code personnel inventory in five years? Ten years? If a shortage of personnel in a P-code category is expected to exist in the grade of commander ten years from now, should action be taken immediately to enroll the necessary number of lieutenants or should action be deferred for five years and then enroll lieutenant commanders? What criteria should be used for selection of education alternatives?

These are only a few of the questions which face naval management in scheduling student inputs to postgraduate programs. The conclusions of a board convened to answer these questions (among others) for naval management are contained in a document entitled "Report of a Board to Study Billet Requirements and Grade Distribution in the Subspecialty and Specialty Areas in the Navy." [Ref. 1]. Irrespective of the quality of the conclusions contained in this report, the lapse of time since they were published in 1964 leaves their validity at the present time open to question. However, no replicable methodology is provided in the report for review of the conclusions with respect to changes in officer retention rates, P-coded billet requirements or alternative management policies. The conclusions presented are specified to be "optimal" but the criteria on which this claim was based is not explicitly stated in the report. Review of the reported conclusions by

naval management would require either the convening of a new board to update these conclusions or development of a replicable process by which updated information could be generated for management consideration.

The development of a replicable, explicit methodology for generation of information basic to postgraduate program management was the subject investigated in this study. Basic to this development was the application of modeling and mathematical techniques identified with the discipline of Operations Research/Systems Analysis. Through these techniques a simplified mathematical model of relations in the "real world" system confronting naval management was devised where changes in retention rates or management policy may be investigated. However, the usefulness of these techniques is dependent on management understanding and accepting the simplified descriptions as a "reasonable" explanation of the "real world" system. The formal model is presented in Appendix A.

The content of this report is an explanation of a descriptive model developed for the evaluation of management decisions related to postgraduate program student input schedules. Since the development was accomplished without the direction of personnel management, care has been taken to explicitly state all assumptions made for system description and simplification. Should management object to any of these stated assumptions, the work is still considered valuable since a point-of-departure for development of an alternate model will have been established.

II. PERSONNEL SYSTEM ANALYSIS

For model development, the important elements of a system and their interrelations must be determined. P-coded billet levels, P-coded personnel requirements and postgraduate program input schedules (manpower and capital) represent the main elements in the personnel system under investigation in this study. Their interrelations provide the basic structure of the model.

A. P-CODED BILLETS

Procedures for identification of billets requiring advanced technical/managerial education are existent in the Navy and a current listing of these billets is available to personnel management [Ref. 2]. Past experience has shown that the content of this listing changes over time. These changes represent a restatement of the positions to which personnel management must detail qualified officers. In some instances the changes have been compatible with prior education planning and personnel have been available for allocation to the new billets. This has occurred when the restatement represented no net change in the number of billets written for a specific type of officer or when the change was related to a seniority level which was not an active constraint or "controlling grade" in the education plan. When the changes have related to a controlling seniority level, alteration of education plans have been necessary.

For example, assume a new billet is identified and added to the listing. This billet is related to some specific educational and professional qualification grouping of officer personnel. The management actions necessitated by the additional billet for this officer community (P-coded/professional qualification group) will depend on the grade or seniority level specified in the new billet. In order to provide a sufficient inventory of qualified officers in another seniority level, the education plan in existence may have resulted in an excess number of P-coded officers in the affected seniority level. In this case, personnel management can continue to operate under the previous education plan. However, if the new billet is identified in a critical or controlling seniority level on which the previous education plan was based, then additional officers will need to be enrolled in postgraduate programs to <u>eventually</u> provide a new acceptable personnel inventory level.

Adjustment of the P-coded officer inventory requires a minimum time equal to the time to enroll additional students in postgraduate programs and time for completion of the required course of study. The time-lag from billet addition to inventory adjustment may be much longer than this minimum delay if junior officers are programmed for postgraduate study and must "age" for several years after completion of education to attain the requisite seniority level. Had the change to the billet listing been anticipated, the education plan could have been revised to decrease the delay between billet restatement and personnel inventory adjustment.

The model developed in this investigation can be used to derive postgraduate education plans based on anticipated (expected) future billet levels for specific P-coded/designator communities of officer personnel. When planning is based on the expected number of billets in specified seniority levels, the time delay between a change in aggregate billet levels and adjustment of officer inventory levels can be reduced. In addition, management can explore alternative education plans based on the expected future billet levels to determine a best or most desirable plan over time.

Techniques for aggregation of the current P-coded billets into homogeneous groupings exist in officer personnel management and are suitable for model development. The basis of these techniques is to aggregate over the following three elements in the billet description.

1. <u>Designator code</u>

   The designator code is a qualitative description of the professional naval qualifications required of an incumbent in the billet. For example, the designator code 3100 specifies a requirement for a Supply Corps Officer.

2. <u>Grade code</u>

   The grade code is a quantitative description of the level of professional naval experience required of an incumbent in the billet; such as a lieutenant, commander, etc.

3. P-code

The P-code identifies the academic area associated with qualification for the advanced technical/managerial requirements of the billet.

Aggregation by use of these elements results in summation of those billets in which an officer with the appropriate codes would be qualified for assignment. For a given designator code and P-code, the grade codes identify sets of billets over seniority levels. When the years of commissioned service for promotion are specified, these sets of billets represent the number of billets for the community within periods over a thirty-year career.

An alternative aggregation technique for the billets in a "community" or common P-code and designator grouping has recently been developed by the Career Planning Board in the Bureau of Naval Personnel. In this technique, the timing of non P-coded assignments required for professional naval qualification of officers in the community is integrated with officer utilization in advanced technical/managerial billets. The result is a refined career pattern where assignment of P-coded officers to advanced technical/managerial billets and professional naval duty throughout a career is expressed as a function of years of commissioned service. A pattern is determined for each community defined in the billet listing which specifies P-coded billet assignment periods over a thirty-year career. For example, the pattern may specify that P-coded officers in the community will be assigned to

advanced technical/managerial billets during the periods represented by 7-10, 12-15, 16-19, 21-24, and 26-28 years of commissioned service. These periods, or intervals of years of commissioned service, will be called utilization-stages. Each billet written for an officer requirement from the community is allocated to one of the defined utilization-stages. Any officer in the community is eligible for assignment to a billet in a utilization-stage if his years of commissioned service are within the interval specified in the career plan. If the officer does not fall within one of the defined periods for P-coded billet assignment, he is considered to have professional service requirements which preclude his assignment to an advanced technical/ managerial billet.

This latter aggregation technique specifies the number of billets in each utilization-stage and the upper and lower limits of the years of commissioned service for the level of naval experience desired in the billets. This approach considerably simplifies the determination of personnel requirements as a function of billet levels discussed in Section II. C.

The effect of either aggregation technique is to provide a set of billet groups differentiated by the level of experience required of an incumbent. A determination of the number of billets in utilization-stages and the career timing for assignment of officers to P-coded "community" billets is basic to the model developed.

B. BILLET PROJECTION

The model developed in this investigation does not require any specific assumptions concerning the growth of billet levels over time. The model is based on a finite projection horizon which is partitioned into a discrete set of planning points (for example, the beginning of each year). It is assumed that management can express a set of disjoint utilization-stages within a 30-year career and the anticipated billet levels in the utilization-stages at each planning point. The definition of the utilization-stages does not need to be identical for all planning points. However, at each planning point the individual utilization-stages cannot overlap, i.e., no two utilization-stages at a time point can contain a common experience level.

It must be noted that the finite projection horizon is not the same as the schedule horizon which education plans are to cover. The projection horizon over which anticipated billet levels must be specified will depend on the conditional expectations and method for selection of optimal activities. For example, assume management desires to derive an optimal education plan over the next five years for a post-graduate program of two years in length. The minimum projection horizon will be seven years; i.e., the schedule horizon plus post-graduate time. The maximum projection horizon will be the minimum horizon plus the years of commissioned service of the greatest seniority in the utilization-stage description. If officers with thirty years of commissioned service are included in a utilization-stage, the maximum projection horizon would be thirty-seven years for the example.

Techniques for projection of P-coded billet levels are currently under investigation in the Navy [Ref. 3]. Methods for predicting growth by academic area for a point ten years in the future are being explored. Although such projections are valuable, they do not specify how growth will take place through the ten-year interval. One possible assumption is that the growth rate is identical for all utilization-stages in a community and that the growth path is linear over the ten-year period. After reaching the ten-year level, it may then be assumed that requirements are constant for long-range planning. Management may have reason to postulate requirements projections different than the above or may wish to investigate the impact of various assumptions concerning future requirements projection. The statement of billet levels over the planning horizon does not appear explicitly in the model. It is required to determine the personnel requirements in the utilization-stage at planning points as a function of anticipated billet levels.

C. PERSONNEL REQUIREMENTS

Given that management establishes future P-coded billet levels in the utilization-stage as specified above, what does this imply with respect to the requirements for P-coded personnel in the community? To answer this question it is assumed that management desires to fill all projected billets with P-coded personnel whenever possible. This does not mean that minimum personnel requirements are identical to projected billet requirements. As long as a P-coded officer is on active

duty he is considered to be in the personnel inventory. However, he may not be continuously available for assignment to an advanced technical/managerial billet. For example, he may be hospitalized or in between assignments in a transient status. Of greater importance, he may have a requirement to serve in a billet associated with his primary professional qualification such as flying aircraft or "driving" ships. The model assumes that the minimum personnel requirement in each utilization-stage is proportional to the number of billets identified.

These proportionality constants depend on whether the utilization-stages are defined by translation of grade-codes into years of commissioned service or by a career pattern developed by the Career Planning Board. When the utilization-stage is defined by the inclusive years of commissioned service for each grade, the effect of nonavailability of P-coded officers during required professional service must be evaluated. The resultant relation between billets and personnel requirements will include a grade factor similar to those derived in the earlier study. [Ref 2] The rationale behind a grade factor is basically that billet requirements must be weighted by the ratio of total time in grade and available time in grade to determine minimum personnel requirements. For example, assume that officers normally spend six years in the grade of commander and that for surface line commanders there are professional service requirements which preclude assignment to P-coded billets for a total period of 3.6 years in grade. This means that in the surface line community, officers are available for service in advanced technical/

managerial billets for a period of 2.4 years. The grade factor for P-coded surface line commanders is the quotient of 6 and 2.4, or 2.5 and the minimum personnel requirement is at least 2.5 times the number of billets. The validity of grade factors in determination of personnel requirements rests on two assumptions which are frequently not brought to the explicit attention of management.

The first is that the distribution of P-coded officers is fairly even throughout the year groups in grade and that requirements are fairly stable over time. If these assumptions are not made, it is not difficult to hypothesize situations where the number of persons in the grade inventory equals the minimum personnel requirement computed with grade factors and all will have served the maximum time in P-coded billets. Thus, no officer would be available for assignment to a P-coded billet without violating stated professional service requirements or restating the minimum personnel requirement at a higher level for planning purposes.

The second assumption which is implicit in the use of grade factors is that replenishment of the grade inventory will largely be by promotion of P-coded personnel into the grade and not by receipt in grade from a postgraduate program. In the example above, if management inputs a significant number of surface line commanders from the postgraduate program directly into P-coded billets during the last 2.4 years in grade, the grade factor is invalid. If this direct input was the

primary source of P-coded surface line commanders, minimum personnel requirements would be approximately the grade billet level.

The definition of utilization-stages based on the integrated professional/technical career patterns developed by the Career Planning Board removes the requirement for statement of grade factors in establishing minimum personnel requirements. No grade factor is required since the utilization-stages are defined in such a manner it can be assumed that all P-coded officers in the utilization-stage inventory are available for assignment to required billets. Management need only be concerned with provision of a "safety" factor, when stating the relation between personnel and billet requirements, for conditions which may temporarily preclude assignment of personnel to P-coded billets. For example, hospitalization or delays in transit between duties. Factors of this sort are in use in military personnel planning and are called Transient, Patient, and Prisoner (TPP) allowances. The minimum personnel requirement for utilization-stages based on integrated professional/technical career patterns would be the number of billets plus the number of additional officers authorized to cover the TPP contingencies.

For model purposes, it is assumed that management can define grade factors and TPP allowance factors as necessary to state a minimum personnel requirement for each utilization-stage. These minimum personnel levels appear directly in constraining relations imposed on personnel inventory projections in the model.

D. STUDENT INPUT/EXPECTED INVENTORY RELATIONS

Naval officers on active duty are assigned to postgraduate programs for acquisition of advanced technical/managerial qualifications. On successful completion of the program, an officer is assigned a P-code and becomes an addition to the personnel inventory of the appropriate community. The officer continues in the personnel inventory (getting older each year) and eventually leaves the community inventory. The reasons for departure are many; retirement, resignation, death, or medical disability to mention a few. The complex nature of failure to successfully complete the postgraduate program and the eventual departure of P-coded officers from the personnel inventory makes it impossible to state with certainty what relation a student enrollee has on future P-coded personnel levels.

To explore what may be said concerning this relationship, assume an officer is assigned to a two-year postgraduate program. After a period of time, say one year, what can be his status? If the officer is on active duty, he is one year older and has one additional year of commissioned service. Given he remained on active duty, he may for some reason have dropped from the program without attaining the advanced technical/managerial qualification. Another possibility is that the officer is continuing into the second year of the postgraduate program. A final alternative is that he may have proceeded at an accelerated pace and completed the postgraduate program for P-code qualification in the one year. Thus, it is possible that the appropriate community has received an additional officer.

What may happen to this officer after an additional year has passed? The answer depends on his status at the end of the first year. If he had dropped from the program without the P-coded qualification, it is assumed that he is of little further concern for P-code personnel management. If he continued in the education program, he may have received his P-code designation and be entering the personnel inventory, or, he may have failed to acquire the P-code designation in this second year and no longer be of interest to P-code personnel management. Finally, if he entered the P-code inventory at the end of the first year, he may either still be in the inventory or may have been lost from the inventory during the previous year. Continuing in this manner, a set of descriptions of what may happen to this officer can be developed where each description of what he can do over time will be called a "path."

1. Student Continuation Estimates

Given a student officer is assigned to a postgraduate program or is in a postgraduate program, the student continuation estimate is defined to be the expectation that the officer will show satisfactory progress through a unit period of time and continue in the program during the next unit period of time. The phrase unit-period is used since any convenient time interval may be selected by management; it need not be a year as in the example. It is important to note that the estimate of student continuation is conditioned on the assertion that the officer is assigned to the program or is in the program at the beginning of the period and represents a conditional expectation.

For a particular student this estimate would be based on his educational background, time elapsed since entry into the service and past progress in the postgraduate program. If an arbitrary officer is under consideration so that individual educational backgrounds are unknown, this estimate could be based on years of commissioned service and number of periods satisfactorily completed in the postgraduate program.

2. P-Code Qualification Estimates

These estimates are defined to be the conditional expectations that an officer in the postgraduate program at the beginning of a unit time interval will complete the course during the period and enter the P-coded personnel inventory at the end of the period. Similar to the student continuation estimates, these estimates suppress individual knowledge about the student and are assumed to be a function of the years of commissioned service of the officer and the time in the program.

3. P-Coded Officer Continuation Estimates

These estimates are defined to be the conditional expectations that an officer in the P-coded inventory of a community at the beginning of a unit time interval will continue in the P-coded inventory at the beginning of the next unit time interval.

In the introductory example it was shown that at the beginning of the third year, there were two "paths" by which an officer could be expected to be an asset in the inventory. One was through one year of study and continuation in the active inventory for at least one year.

The other was through two years of study and successful completion of the postgraduate program. Except for this difference in possible routes, the officers have the same number of years of commissioned service and entered the postgraduate program at the same time. Is the future expectation that an officer will continue in the personnel inventory the same for both paths? In general the answer is no, due to acquisition of a minimum service requirement by personnel attending postgraduate programs. The minimum service requirement limits the voluntary departure of an officer from the personnel inventory for a period twice the length of time spent in the education program. For example, if the officer in the above example takes the accelerated path, he will acquire a minimum service requirement of two years and will already have served one of these during the second year of education in the "normal" path. Three years after the officer is assigned to the postgraduate program there is an expectation that the officer will be in the personnel inventory by both paths. However, for the accelerated path he would have no remaining minimum service and may voluntarily depart as opposed to three years remaining minimum service from the other path.

The P-coded personnel conditional continuation estimates are assumed to depend on the years of remaining minimum service as well as years of commissioned service and P-code qualifications.

4. Linearity Assumption

The above expectations have been defined with respect to one officer. If two officers with the same number of years of

commissioned service are assigned to the postgraduate program at the same time, do the expectations for these officers as defined above have the same values? It would appear quite plausible that if management reviews the individual academic and professional backgrounds of these two officers, different values for these conditional expectations would result. However, the development of future student input schedules based on unique expectations for specific officers is not possible. Many of the officers who will be assigned to postgraduate programs in the future are not even in the service at the time of long-range planning.

It is assumed that qualifying standards exist for assignment to a postgraduate program and that any officer meeting these qualifications is equally likely to be detailed to the program. The conditional qualification and continuance expectations are defined to be those representative of an "average" officer who is considered qualified for the program to suppress dependence on individual backgrounds. This is a simplification of the "real world" system in that postgraduate selection boards attempt to select those persons with the highest expectations of qualification and continuance for enrollment. It must be noted that the error introduced by the simplification is an error in favor of conservative management, since the inventory expectation is increased by the selectivity of the board. (Assuming the selection board does identify the officers who have the highest expectations.)

It is also assumed that the number of postgraduate qualified officers who are eligible to join any particular P-code community is

large compared to the number who will be scheduled into a particular postgraduate program. Note that this assumption is with respect to a specific program and does not say that the number of postgraduate qualified officers is large with respect to <u>all</u> program requirements. This problem is discussed in Chapter IV. The third assumption related to the conditional expectations is that an officer succeeds in P-code qualification and remains in the inventory independent of the success and career actions of his contemporaries. Thus, the expectations related to one "average" officer are independent of the actions of another "average" officer.

A final assumption concerning the behavior of the "average" officer is that expectations related to his continuance in the P-coded personnel inventory are independent of whether or not he is assigned to a P-coded billet when in a defined utilization-stage. This assumption is required since system interdependencies will result in expected utilization-stage inventories in excess of personnel requirements. It could be modified by assigning separate continuation expectations to excess personnel if information on the relation between continuance and non-utilization is known.

Under these assumptions, the <u>expected inventory</u> level at a future time-point has a linear relation to student input schedules. The number of qualified officers in the inventory at a future time is the product of the expectation that one officer will be in the inventory (given a student is assigned to a postgraduate program) and the number of students assigned.

5. <u>Activity Definition</u>

The relation between assignment of one officer to a postgraduate program and the expectation that a P-coded officer will be in the personnel inventory at a future point-in-time can be derived from the above <u>conditional</u> expectations. This expectation is the total expectation that an officer input to a postgraduate program will be P-code qualified and remain in the personnel inventory at least until the time in question.

In the introductory example, the total expectation that an officer will be in the personnel inventory after one year is the expectation that a student input will take the accelerated path. After two years, the total expectation will be the sum of the expectations that a student input to the postgraduate program will take either the accelerated path or the normal path. This result follows from the fact that he can take one path, the other path, or neither path, but he cannot take both. The expectation that he will take any one path over time is the product of the conditional expectations that he will follow each step in the path through time.

The total expectation that an officer with a specified number of years of commissioned service will be in the P-coded personnel inventory at a time-point in the planning period, given that he is assigned to the postgraduate program with a specific number of years of commissioned service at a time-point in the planning period will be called an <u>activity</u> for model purposes. This definition is broad and covers

many situations for which the expectation would be identically zero. For example, the expectation that the officer will be in the P-coded inventory at a time-point prior to his assignment to a postgraduate program is identically zero. Also, the expectation that an officer will be in the personnel inventory three years after his admission to a postgraduate program with a total number of years of commissioned service different than the number on entry to the postgraduate program plus three years would be identically zero. The definition of an activity was expanded to include these impossible situations as well as all possible situations for model completeness.

The set of all activities during the planning period, when coupled with the linearity assumption of constant expectations to scale, represents the information relating student input schedules to the expected personnel inventory at any time-point in the planning period. Any student input schedule may be translated into expected inventory levels through the information in the set of activities. This information relates student inputs and expected personnel inventories based on years of commissioned service and the time-lag between postgraduate program entry and planning time-points. A utilization-stage may include several years of commissioned service and some seniority levels may not be represented in any utilization-stage for a particular community. The activity set defined above is rearranged for model purposes so that those activities related to utilization-stages are combined and those not required are omitted. This transformation of the activity set into a

utilization-stage "technology" expands the number of alternative ways in which expected personnel levels may be related to utilization-stage personnel requirements. The question of what relation <u>should</u> exist between personnel requirements levels and expected inventory levels must be answered before the relation of student input schedules and personnel requirements can be stated. This relation is dependent on a statement of management objectives and is discussed in Chapter III.

E. INITIAL SYSTEM CONDITIONS

The personnel system represented by the model is assumed to be in operation and initial data with respect to inventory levels and post-graduate students in the community known. These conditions have a direct influence on expected inventory levels at future planning points. For planning points early in the planning period, these initial conditions may be the only factors relevant to the expected inventory levels if a lengthy postgraduate program is involved. For example, if the post-graduate program is of three years in length and accelerated paths are nonexistent, no new student input will be available to compensate for expected shortages projected from the initial student and qualified personnel inventories. This problem will be of concern in the expression of system relations in Chapter III.

III. OBJECTIVES AND MODEL FORMULATION

In Chapter II, a relation between billets and personnel requirements was determined. Also, the activities relating initial conditions and future student input schedules to expected personnel inventory levels were specified. The relation between expected personnel levels and projected personnel requirements depends on how management desires to operate the system.

Given that some relation reflecting this objective exists, it is not obvious that management will find all the non-zero activities in the planning system desirable. The set of activities developed which relates student input schedules to future inventory expectations represents all student input alternatives. For the same reasons that certain seniority levels of naval officers may not be available for assignment to P-coded billets, they may not be available for postgraduate study. The model developed provides management with the option to preclude postgraduate assignments for those seniority levels (in terms of length of commissioned service) not desired in the planning schedule.

After the exercise of this management prerogative, there may still be many alternative input schedules which will satisfy the system relations. The criteria for selection of a "best" or "optimal" planning schedule is dependent on additional goals of system management.

A. EXPECTED INVENTORY/PROJECTED REQUIREMENTS RELATION

The model assumes that management desires to schedule postgraduate student inputs over a planning period so that expected personnel levels will at least equal the projected personnel requirement in each utilization-stage at future time points. For every utilization-stage at each projection point, a constraint is included to relate the expected personnel inventory and personnel requirement. The exact form of these constraining relations is dependent on the introduction of artificial activities which insure that the set of system relations is consistent.

As noted in Chapter II, when a lengthy postgraduate program is required for P-coded qualifications, initial conditions may determine the expected personnel levels early in the planning period. If no student input activities are available to correct expected shortages, the model constraint may be inconsistent since the expected inventory would be less than stated personnel requirements. To preclude this possibility, a hypothetical activity was introduced for each utilization-stage which may be considered as a source for direct procurement of P-coded personnel. When these artificial activities are at a positive level in a postgraduate program input schedule, the magnitude of the "direct procurement" will be the expected shortage of personnel in the associated utilization-stage.

System interdependencies will generally result in expected personnel levels in excess of stated requirements in many utilization-stages

over time. To permit statement of equality constraints in the model, a set of excess personnel variables (one for each utilization-stage at each time-point) was included. When any postgraduate plan includes an excess personnel variable at a positive level, the magnitude represents the expected number of P-coded personnel who will be in excess of minimum requirements in the utilization-stage at the associated planning time-point. If the excess personnel variable remains at a positive level over the planning period, it indicates that additional billets for P-coded officers may be assigned in the utilization-stage with no modification to the education plan.

With the two sets of artificial variables, the system relations between personnel requirements and expected inventory levels may be expressed as equalities. The expected personnel inventory from projection of initial data and the education plan plus "direct procurement" and less "excess personnel" must equal the stated minimum personnel requirement for each utilization-stage defined at every planning time-point. In this form, management has information on expected personnel shortages and excesses directly available from the system model.

Statement of the system relations in this manner guarantees that a solution schedule exists. One solution is for no inputs to postgraduate programs over the planning period, i.e., when initial personnel and student data is projected over the planning period, "excess personnel" or "direct procurement" variables are scheduled for each utilization-stage as appropriate. This schedule would be most

undesirable and an additional objective must be defined for the system so student input scheduling will replace "direct procurements" when possible.

B. UNDESIRABLE ACTIVITIES

As defined in Chapter II, an activity is the relation between a student input and a future P-coded officer expectation. These activities are differentiated with respect to the years of commissioned service and planning time of a student enrollment, and the years of commissioned service and planning time of the inventory expectation. There will be sets of activities related to each seniority level for inputs over the planning period. Consider the surface line officer (designator code 1100), Operations Research (P-code 8501 P) community. One set of activities over the scheduling period would relate postgraduate input of commanders with fifteen years of commissioned service to expected inventory levels. Professional service requirements, such as destroyer command, may make the assignment of these officers to postgraduate study undesirable.

An option to preclude the scheduling of seniority levels not acceptable for postgraduate study was provided in the model. Schedules with postgraduate inputs in undesirable seniority levels are treated similarly to the solution schedule where no student inputs are programmed. This technique was to define the objective for selection of an "optimal" schedule from the set of feasible schedules and use this objective to bias undesired activities to insure that acceptable activities are favored in scheduling whenever possible.

C. OPTIMAL SCHEDULE CRITERION

Given that management has the capacity to restrict undesired schedules which satisfy the system relations, there will still be a considerable number of acceptable postgraduate schedules in the solution set. What criteria should be used to select a "best" schedule for postgraduate input planning?

In the introduction, it was stated that manpower and budgetary resources are expended in operation of the postgraduate programs. In using the model, management can preclude undesirable postgraduate inputs and, therefore, the alternative schedules in the remaining set of solutions will represent combinations of acceptable activities. For every schedule there is an associated cost represented by a projected stream of expenditures over the planning period. The selection criterion prescribed in the model is to select the minimun cost schedule from the set of acceptable solutions.

What is the cost of a postgraduate input schedule? Can it be represented purely in terms of dollar expenditures for program operation? How may it be estimated as a function of the input schedule? These questions are of central concern to the statement of an objective function for model purposes. Simplifying assumptions made to answer these questions will determine the form and complexity of the cost estimator function utilized in the model. The accuracy of this cost estimation function, at least with respect to properly ordering solution schedules in terms of relative cost, should be rigorously investigated prior to model utilization for real-world decisions.

As a basis for investigation of schedule cost estimating relations, consideration was given to the marginal cost associated with addition of a student to a postgraduate program at a point-in-time. The marginal cost of an additional student was subdivided into the cost of the officer "procured" for postgraduate education and the additional cost for program operation. The cost of an officer is associated with the sacrifice of benefits which could be received if the officer was assigned to an alternative duty and will be called an <u>opportunity cost</u>. The program cost is the additional dollar expenditure required for postgraduate program operation with the additional student.

1. <u>Opportunity Cost</u>

The opportunity cost of a student in a postgraduate program is the foregone benefits which could be received if the officer was assigned to an alternate billet. This opportunity cost could also be viewed as the cost of procurement of an additional officer with the same qualifications to fill the billet in his absence. It is important to note that opportunity costs are not reflected in dollar expenditures for postgraduate program operation. If opportunity costs exist, the minimum total cost schedule will not necessarily be the minimum dollar cost schedule.

The concept of an opportunity cost is operative in the personnel system at present. The restriction of P-coded personnel utilization in certain seniority levels from advanced technical/managerial assignments is an expression of an opportunity cost. In these instances

management has judged that the benefits received if these officers serve in P-coded billets are small in comparison to the professional service benefits foregone. Also, management evaluation of an opportunity cost is basic to the notion of an undesirable activity.

The model developed provides an option for management to assign large opportunity costs to undesirable activities and to expected shortages ("direct procurement" activities). Due to the assignment of an artificially high cost, the minimum cost schedule will exclude undesirable activities and expected shortages whenever possible. The relative values of these opportunity costs will determine whether expected shortages replace undesirable student assignments or vice versa.

What is the opportunity cost for an officer whose assignment to postgraduate study is acceptable? It would be zero if there is an excess of officers with his qualifications so that no productive billets are unfilled. In general, however, officers do not exceed productive billets and the assignment of an officer to a postgraduate program requires the "procurement" of a replacement to fill a billet. In this case, the officer's full pay and allowances provide a dollar cost estimate of the opportunity cost of a student in a postgraduate program.

It is beyond the scope of this investigation to resolve the complexities associated with determination of opportunity costs in postgraduate assignments. It was assumed in the model that management can estimate the opportunity cost for an officer in a postgraduate program

as a function of his length of commissioned service and professional qualifications. It was further assumed that the range of personnel requirements over which a specific community schedule would apply to any seniority level is small in relation to the numbers of officers in the active inventory. If unfilled billets are spread throughout the Navy, the opportunity cost for a student is independent of the number of similar officers in the schedule. A final assumption was made that the opportunity cost estimate was constant over the class of unfilled billets (foregone benefits) resulting from postgraduate assignment. These assumptions permit computation of schedule opportunity costs as a linear function of student inputs.

2. <u>Program Costs</u>

Estimation of program costs as a function of student input schedules is no less complex than the estimation of opportunity costs. The investigation of program cost estimation was separated into two areas of consideration. The first is the cost as a function of the level of program operation at a point-in-time. The second is the cost related to changes in program levels between adjacent time-points.

It was assumed that management can estimate the budgetary costs for postgraduate program operation at a point-in-time as a function of the number of students in the program. It is not obvious that this cost estimate has a linear relation to the program operating level. If it is nonlinear as suspected, then evaluation of student input schedules will require knowledge of total program levels over time. Program levels

associated with the community schedules in question can be computed as a function of the schedules and initial student data. However, the total program level at a time-point may depend on the student input schedules for several common P-code communities. For example, the program level for Operations Research at a point-in-time is dependent on the student input schedules for the surface line community, the aviation community, and various restricted line and staff corps communities, as well as Marine Corps, Army and Coast Guard student enrollment schedules. Therefore, the environment or range of postgraduate program levels on which the specific community schedule costs would depend is unknown.

A similar problem is encountered in evaluation of program variations over time. The total variation between time-points as a function of the specific community schedules will be unknown due to the lack of information on other community schedules. These problems in computation of schedule costs related to total program levels over time suggest future study to explore a master planning system for postgraduate programs, using sub-system models similar to the one developed in this investigation.

An alternative to development of the complicated model described above, based on assumed characteristics of program costs, is to define an approximate cost estimating function which is independent of total program levels. The nonlinearity of program level cost estimates may be greatest at low operating levels where a large fixed cost is associated

with the decision to operate a postgraduate program. If this is confirmed, it may be possible to estimate program cost as a fixed cost and a linear cost function of student levels. If management is committed to program operation, the fixed cost for all schedules would be identical and may be ignored. The resultant cost estimating relation for schedule costs related to program level would be independent of the total program level. Total program operation based on all community input schedules is required only for evaluation of the costs of program level variations.

Costs associated with program variation over time represent many intangibles, such as faculty recruitment problems in an atmosphere of alternate hiring and firing, as well as dollar costs. It was assumed that large fluctuations in postgraduate program levels over time are undesirable. However, management may find it difficult to place a dollar cost on variations in total program level. How may program variation costs be taken into consideration if the cost cannot be quantified or without a complicated master planning model?

One method would be to assign a cost to variations implied in the schedule for each personnel community. This cost could be introduced into the model objective function to dampen fluctuations in the program level related to the community schedule. Total program levels over time would be the summation of the smoothed schedules and the total program variation accordingly dampened. This might not be optimal because the total cost of the smoothed program schedule may be greater than the total cost using unconstrained schedules.

Program variation costs are not included in the model. The schedule cost estimator is a linear function of opportunity and incremental costs. The optimal education plan derived with the model minimizes the total cost related to opportunity and program level costs. Consideration of program variation costs was left as a management function exogeneous to the model.

Experience with a program developed to compute approximate optimal schedules and investigate model properties has demonstrated that schedules for a community can contain large fluctuations in program level over time. These fluctuations are most noticeable in the early part of the planning period and are dependent on initial conditions, the expected continuation rates over time, and how sharply the cost per student increases as a function of seniority. It can be shown that for long-range planning, when personnel requirements and utilization-stage descriptions are stable, the student inputs over time converge to an equilibrium condition where fluctuations vanish.

It was assumed that management can evaluate the costs of fluctuations in the total program which result from the combination of student schedules for all communities related to a common academic area. When modifications are necessary to remove undesirable variations in program level, the following corrective actions can be employed. The model was envisioned to provide annual postgraduate input schedules. Since most programs accept student enrollments at least twice a year, management may smooth the total program schedule through redistribution

of student enrollments around the scheduled enrollment times. This redistribution would involve scheduling some inputs for enrollment six months earlier and some six months later than the model planning point. In addition to this smoothing, if total program fluctuations remain undesirable, management may assign additional students to postgraduate programs. The criteria utilized for selection of these additional enrollments, which individual community schedules should receive the augmentation, and how individual community schedules should be redistributed to conform to the smoothed education plan are suggested as subjects for future investigation.

D. MODEL OBJECTIVE FUNCTION

It was assumed that management can evaluate the opportunity and program costs for postgraduate students. The cost per student was assumed to be a function of the seniority and professional qualifications of the student and to be independent of the postgraduate program level. These cost rates may also be assumed to be a function of time if a cost projection capability is available. No cost was assigned to program variations over time for schedule cost estimation within the model.

To relate student cost rates to program input schedules, the <u>expected cost per officer enrollment</u> was investigated. It was assumed that the cost for a student in the program was obligated at the beginning of the unit period on which the conditional student continuation estimates are based. The expected cost of a decision to enroll an officer in a

postgraduate program is the sum of the cost rates for the program periods, each weighted by the conditional expectation that the officer will continue in program during the period, given he is assigned to the program. For example, assume an officer with four years of commissioned service is enrolled in a program of two-year length. The expected cost of this decision would be the cost incurred by a student with <u>four</u> years commissioned service plus the product of the cost for a student with <u>five</u> years commissioned service and the expectation he will continue in the second year of the program. These expected enrollment costs are utilized in the model objective function.

A schedule or education plan derived using the expected cost per student input will represent a stream of expected expenditures over the planning period. In the estimation of the minimum cost schedule, costs at different points-in-time will be compared. Discounting procedures should be considered by management to compare schedule costs on the basis of net present value.

The model objective function in combination with the linear system relationships outlined in Chapter II represent a class of linear models. This class of models is formalized in Appendix A. Which specific model is selected from this class will depend on additional assumptions concerning unit period definitions and the time dependence of student cost and conditional continuation rates. The complexity of these additional assumptions will influence the complexity of the computer program and the statistical information required

for derivation of the optimal education plan. During model definition, management should trade-off the anticipated value of additional information derived from model refinement and the additional costs involved in development of solution programs.

IV. SUMMARY

The purpose of the investigation reported was to develop a model of the U. S. Navy system for enrollment of personnel in postgraduate programs and their subsequent utilization in advanced technical/managerial billets. Information of concern to personnel management for evaluation of the effects of changes in costs, continuation rates and/or assignment policies can be derived from replicable computer programs based on the simplified system relations contained in such a model.

Through analysis of the relations between billet levels and personnel requirements, the model assumed the character of an aggregate education planning system for officer communities with specific academic and professional qualifications. A linear relation was established between education plans and personnel inventory expectations over time. A fundamental objective was imputed to personnel management such that optimal system operation, constrained so the expected personnel inventory will at least equal the stated requirements whenever possible, is based on selection of the minimum cost education plan. Estimation of cost as a function of input schedules was investigated for statement of this objective in the model.

Costs related to a student in a postgraduate program are analyzed in terms of the opportunity cost of benefits foregone in alternate assignment, and educational program costs. For cost estimation, it was

assumed that management can evaluate the cost of a student as a function of his length of commissioned service, including both opportunity cost and incremental program cost. This cost information is utilized to define the expected cost of a decision to enroll an officer in a postgraduate program at a point-in-time. The optimal education plan is defined to be the student input schedule with the minimum net present value.

Costs of variations in the level of postgraduate program operation over time were not included in schedule cost estimation since the total program levels over time are not determined in the model. Evaluation of the costs related to postgraduate program fluctuations remain a management function exterior to the model. Redistribution of student enrollments and assignment of additional officers to the program are suggested as techniques to remove undesired program fluctuations. The investigation of criteria to use in application of these techniques, or the development of a master planning system for centralized cost estimation based on all community schedules related to an academic area are suggested as subjects of future endeavor.

Although management may not be able to determine the exact cost of an education plan, the model can be used to explore costs of alternative policies such as junior vs. senior officer schooling, shifts in utilization descriptions and variations in personnel requirements levels. Further, if the model is utilized for long-range education

planning to a stable requirements description, the optimal education plan will converge to a steady-state, equilibrium schedule for postgraduate program assignments.

For model development it was assumed that the officer resources for enrollment in postgraduate programs are unlimited. For any specified P-code community, this should be valid; but, the total enrollments scheduled from a professional community (designator code) may exceed the number of officers considered qualified for entry to the postgraduate programs. To alleviate this officer shortage in the past, preparatory and refresher courses have been utilized by Navy management to qualify additional officers for postgraduate education assignments. When management reviews the smoothed total education plan, based on billet projections, shortages of qualified officer enrollee's in professional Naval qualification communities may be anticipated. These expected shortages can be used in the model developed as a personnel requirements statement over time, and the schedule for preparatory course operation through the planning period accordingly determined.

APPENDIX A

LINEAR SYSTEM MODEL

1. MODEL STATEMENT

Minimize

$$\underline{C}'\underline{S} + C'_u\,\underline{U}$$

subject to

$$A\,\underline{S} + \underline{D} + \underline{U} - \underline{V} = \underline{R},$$

where all vectors are restricted to non-negative values and the elements of $\underline{S}$ and $\underline{R}$ are constrained to be integral values.

2. NOTATION

T_p : The finite horizon for projection of utilization-stage personnel requirements and P-coded personnel levels.

> t_p : Time-points representing the commencement of the t_p-th unit time interval in the projection period, where $t_p = 1, \ldots, T_p$.

T_s : The finite horizon for the program planning of officer enrollments to postgraduate programs.

> t_s : Time-points representing the commencement of the t_s-th unit time interval in the planning period, where $t_s = 1, \ldots T_s$.

N_p : The number of utilization-stages defined during the t_p-th projection period.

> n_p : An index for the n-th utilization-stage defined in the t_p-th projection period, where $n_p = 1, \ldots N_p$.

$\underline{C}$: A cost vector containing the expected net present cost for an officer enrollment in a postgraduate program.

$\underline{C}_{t_s}$: The t_s-th element of $\underline{C}$, a sub-vector containing the expected net present cost of an officer enrollment in a post-graduate program at planning time t_s. The j-th element of $\underline{C}_{t_s}$ is a scalar representing the expected net present cost for enrollment of an officer during the j-th period of commissioned service in the postgraduate program at planning time t_s.

$\underline{S}$: A vector representation of scheduled postgraduate enrollments over the program planning period.

$\underline{S}_{t_s}$: The t_s-th element of the enrollment schedule, a sub-vector representation of the scheduled postgraduate enrollments at planning time t_s over all seniority levels. The j-th element of $\underline{S}_{t_s}$ is a non-negative, integral valued scalar representing the number of officers in the j-th period of commissioned service scheduled into the postgraduate program at time t_s.

A : A matrix containing the relations between officer enrollment schedules and expected utilization-stage inventories over the projection period.

A_{t_p,t_s} : The (t_p,t_s)-th element of A, representing a partition of the rows and columns of A into sub-matrices containing the relations between expected utilization-stage inventories at time t_p and the scheduled enrollments at time t_s. The (n_p,j)-th element of this sub-matrix in the expectation that a P-coded

officer will be available for assignment to a billet in utilization-stage n_p, given an officer in the j-th period of commissioned service is enrolled in the postgraduate program at time t_s.

$\underline{D}$: A vector containing the expected inventory of P-coded officers in utilization-stages at time-points in the projection period from initial conditions of the system.

$\underline{D}_{t_s}$: The t_p-th element of $\underline{D}$, a sub-vector containing the expected utilization-stage personnel at projection time t_p from initial P-coded personnel and student data. The n_p-th element of $\underline{D}_{t_p}$ is a non-negative scalar whose value is the expected inventory of personnel available from initial system conditions for assignment to billets in the n_p-th utilization-stage at time t_p.

$\underline{U}$: A vector of personnel shortage variables.

$\underline{U}_{t_p}$: The t_p-th element of $\underline{U}$, a sub-vector whose n_p-th element represents the expected shortage of P-coded personnel in the n_p-th utilization-stage at time t_p.

$\underline{C}'_u$: A cost vector containing the expected net present cost of personnel shortages in the projection period.

$(\underline{C}_u)_{t_p}$: The t_p-th element of $\underline{C}_u$, a sub-vector containing the cost for expected utilization shortages in the t_p-th period. The n_p-th element of this sub-vector contains the expected net present cost of a unit personnel shortage in the n_p-th utilization-stage at time t_p.

$\underline{V}$: A vector of excess personnel variables.

$\underline{V}_{t_p}$: The t_p-th element of $\underline{V}$, a sub-vector containing the expected number of P-coded personnel in excess of utilization-stage requirements at projection time t_p. The n_p-th element of this sub-vector is a non-negative scalar variable whose value represents the expected excess of P-coded personnel in the n_p-th utilization-stage at projection time t_p.

$\underline{R}$: A vector of stated personnel requirements in utilization-stages at points in the projection period. These utilization-stage personnel requirements are derived as a function of the projected utilization-stage billet levels.

$\underline{R}_{t_p}$: The t_p-th element of $\underline{R}$, a sub-vector containing the projected personnel requirements in utilization-stages at projection time t_p. The n_p-th element of this sub-vector is the derived personnel requirement in the n_p-th utilization-stage at projection point t_p.

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13. ABSTRACT

A descriptive model of personnel systems existent in the U.S. Navy for acquisition and utilization of officers with postgraduate education is presented in this report. Relations are established between advanced technical/managerial billet levels, presonnel requirements levels, expected personnel inventory levels and postgraduate enrollment schedules. The criterion for selection of an optimal postgraduate enrollment schedule from the set of acceptable schedules which satisfy the system relations is prescribed to be the minimization of net present cost of personnel system operation.

Computational programs based on the mathematical structure of the model developed will provide valuable information to personnel management on expected personnel shortages and critical seniority levels. Personnel management will also be afforded a capacity to rapidly evaluate the effects of changes in continuation rates, program costs and alternative management policies on postgraduate program enrollment plans.

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